Progress towards simulating hyperspectral measurements to differentiate low-, middle-, and high-sensitivity models in CMIP5 (and other research highlights)

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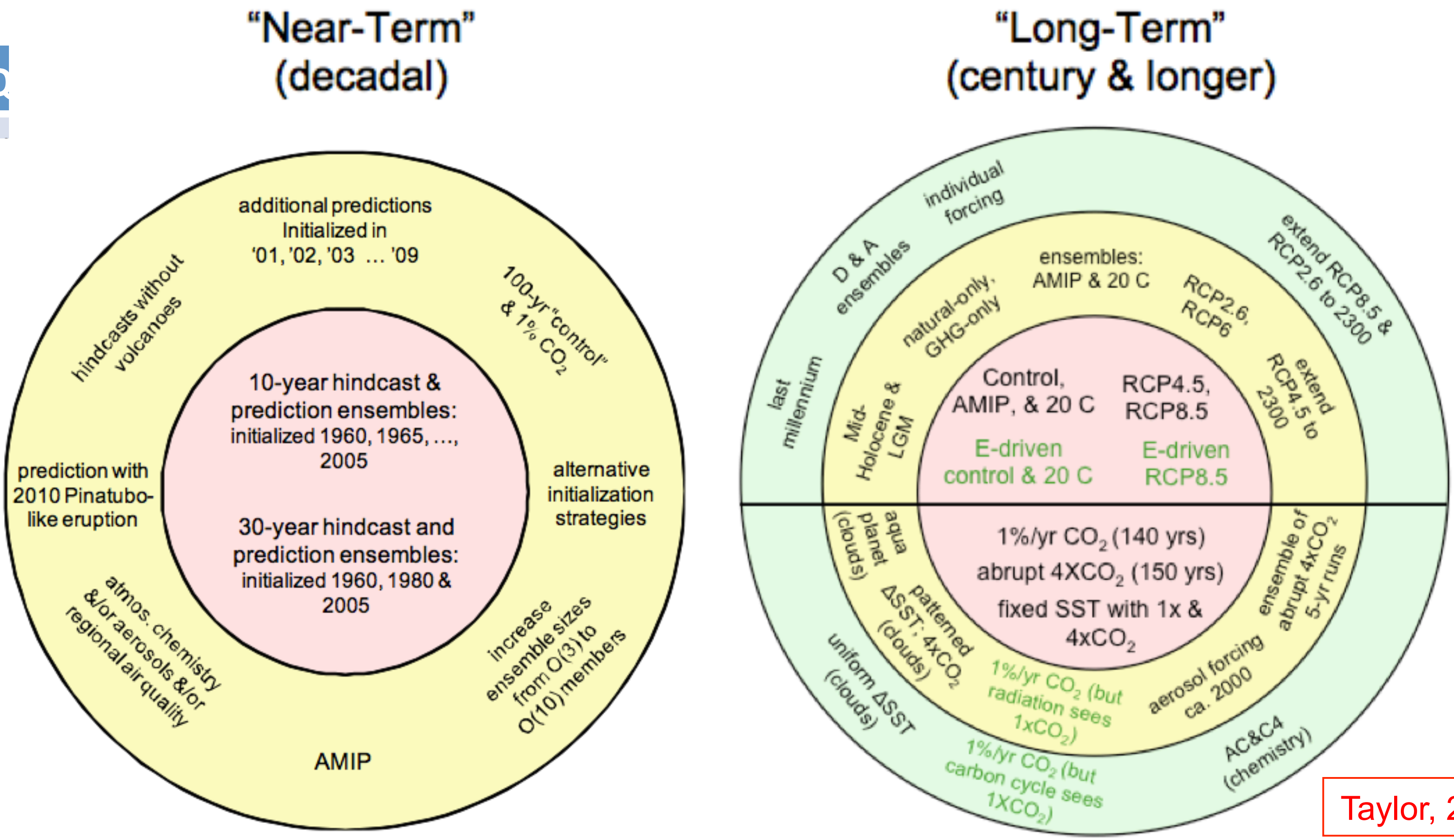
Presentation Outline

- Recap of OSSE tasks and accomplishments.
- MIROC5 vs HadGEM2-ES
  - Broadband
  - Hyperspectral
- Other research highlights
  - Arctic cloud feedbacks
  - Far infrared surface emissivity
- Future directions

Proposed Tasks for the CLARREO SDT

- The Berkeley group has proposed to contribute the following to the CLARREO SDT:
  - Utilization of simulated CLARREO data to estimate change detection time in SW reflectance spectra
  - Interfacing different scenarios (varying forcings and feedbacks) of CCSM3 into the CLARREO OSSE framework.
  - Production of pan-spectral (SW+IR) OSSE spectra.
  - Production and analysis of spectra derived from different orbits (Roberts et al, AGU presentation; Jin et al, JGR, In Review).
  - Development and implementation of tools to produce OSSE spectra based on CMIP5 database.

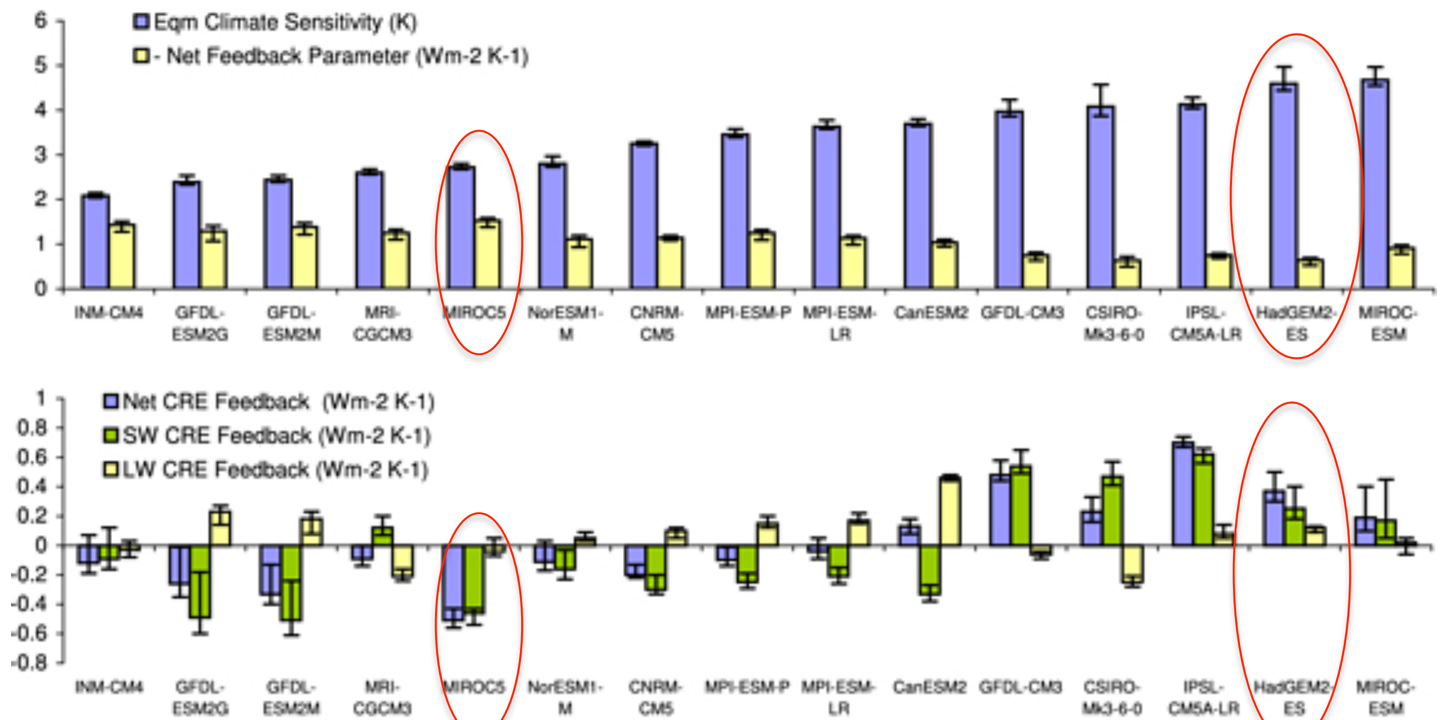
From CMIP5 OSSEs to CLARREO Science Questions



Taylor, 2009

The Range of CMIP5 Climate Sensitivites

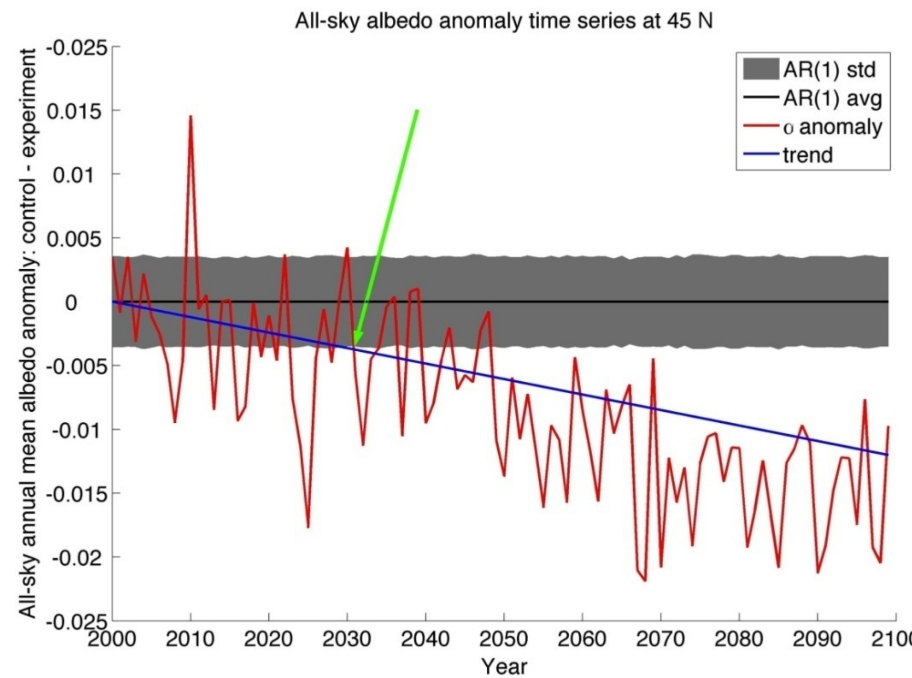
- Range of climate sensitivities in CMIP5 persists.
- How can comprehensive measurements narrow this range?
- Focus here is on MIROC5 vs HadGEM2-ES & RCP8.5 (2.72-4.59 °K/2xCO_2).



Andrews, et al, 2012

Formula for Change Detection

- Time-series differ where the secular trend in the signals exceeds the AR(1) noise envelope.
- Requires estimates of :
  - Natural variability.
  - Uncertainty in noise and trend estimation from a short time series.
  - Measurement uncertainty.



Detection time

Scaling factor for length of record

Std dev of noise process

$$n^* \approx e^{\beta/\sqrt{M}} \left[\frac{3.96\sigma_e}{|\omega_o|(1-\varphi)} \right]^{2/3} \left(1 + \frac{\sigma_{meas}^2}{\sigma_v^2} \right)^{1/3}$$

Measurement uncertainty

Feldman et al, 2013

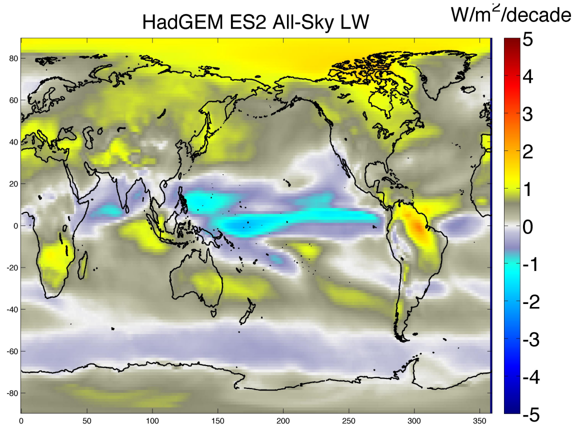
Difference trend

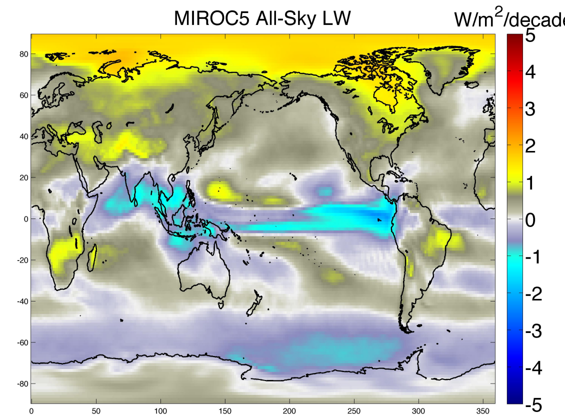
AR(1) of noise process

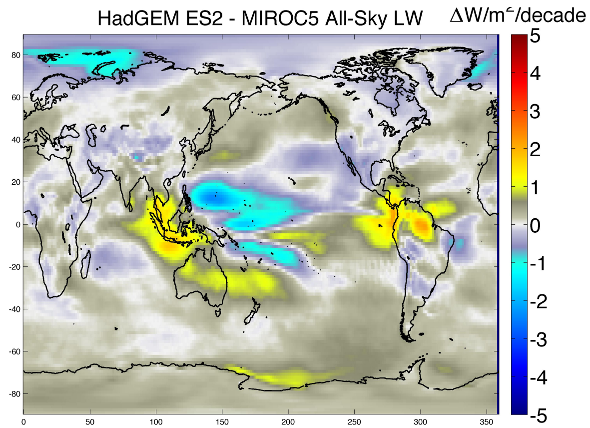
Correlated natural variability

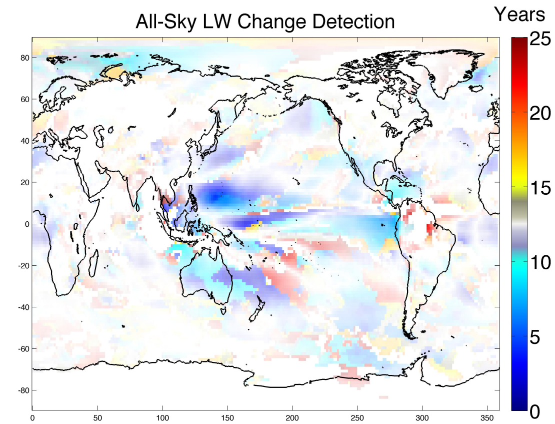
All-Sky OLR Comparison

- Differential response in TWP OLR.
- Detectable with less than 10 years continuous data.



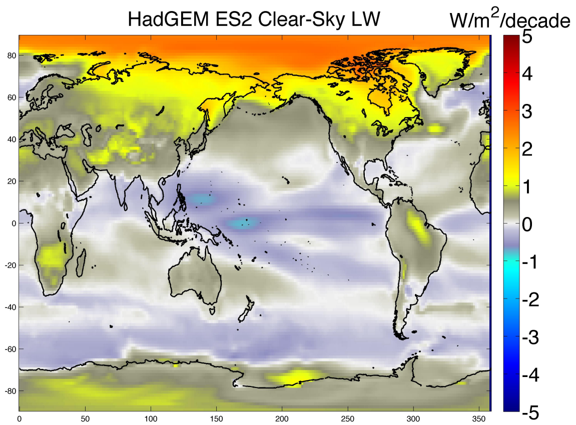


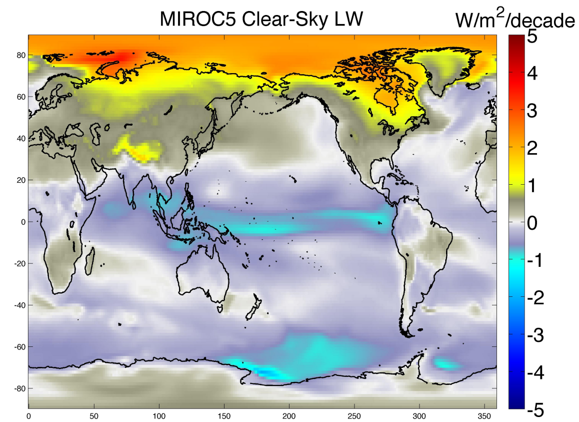


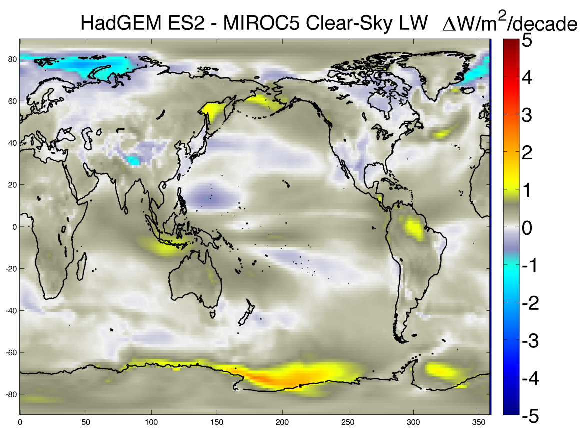


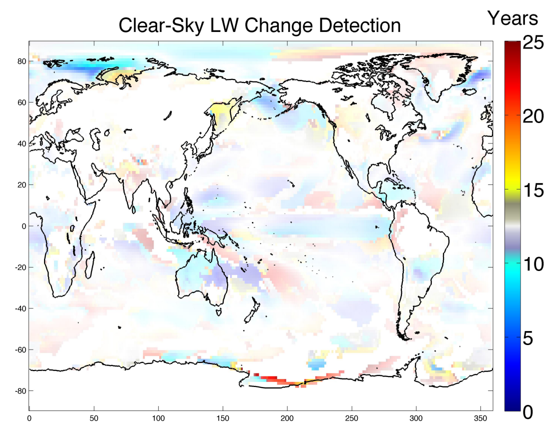
Clear-Sky OLR Comparison

- Ts differences in Arctic lead to differences in OLRC.
- Detectable with less than 10 years of continuous data.



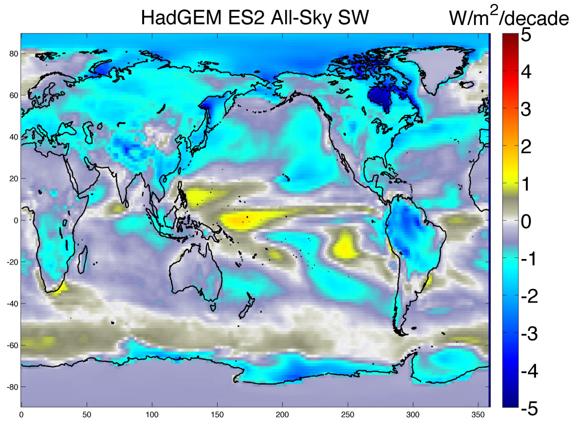


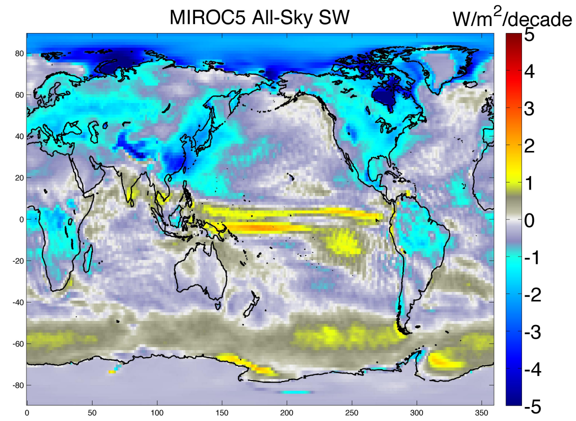


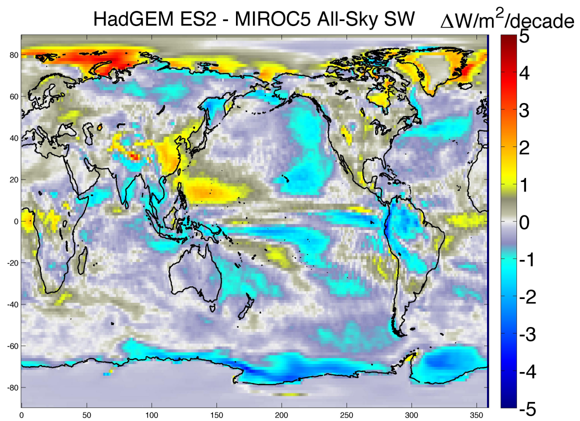


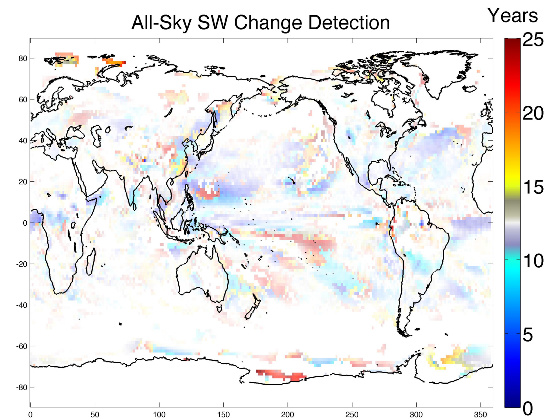
All-Sky SW Comparison

- ITCZ and southern storm tracks.
- Detectable with ~20 years of continuous data



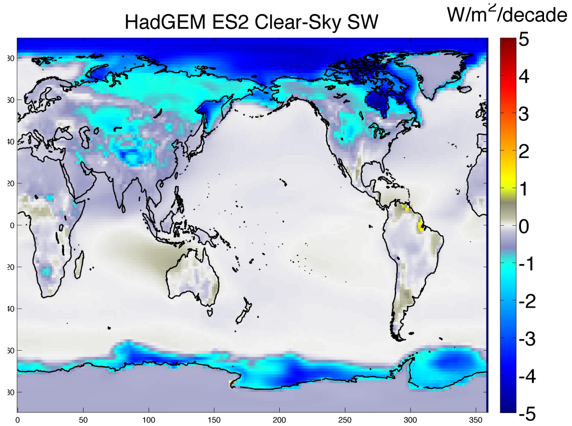


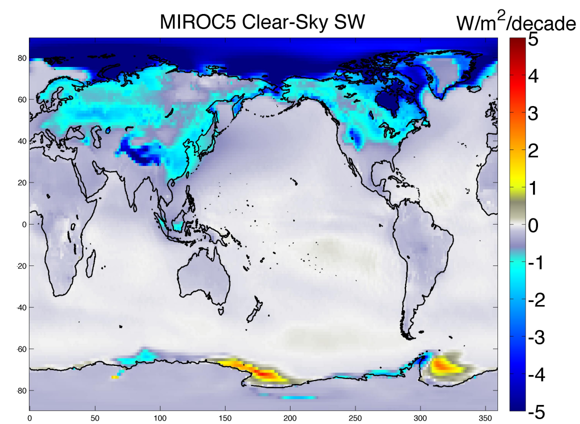


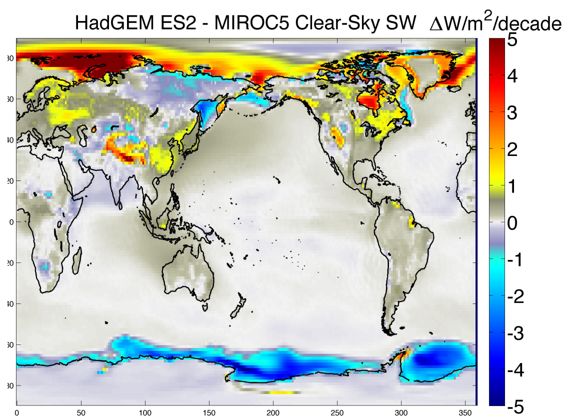


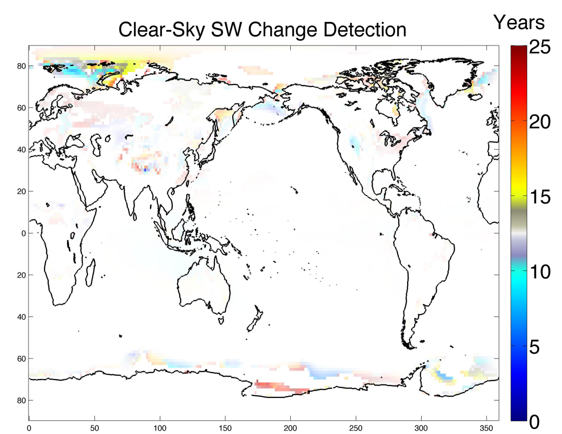
Clear-Sky SW Comparison

- Large differences in SW trends due to sea-ice response differences.
- Detectable with ~ 15 years of continuous data.



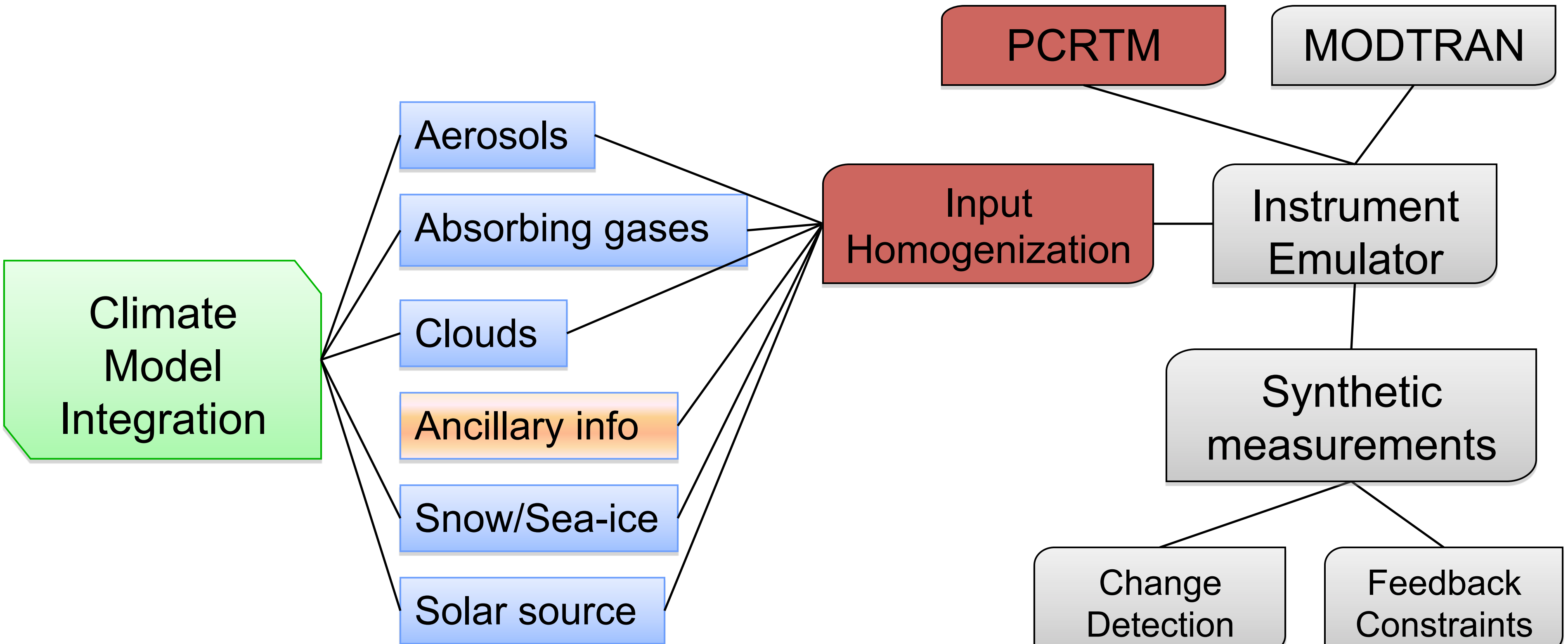






Porting the OSSE Framework to Sample CMIP5

Porting requires the addition of PCRTM and input homogenization

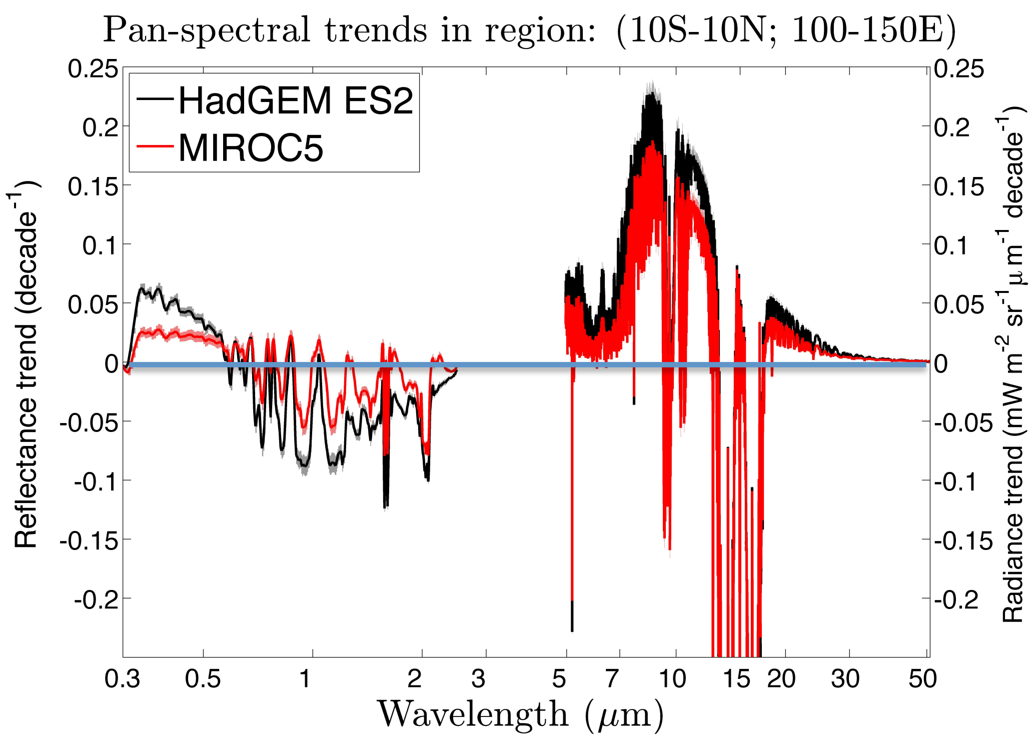


Interfacing with CMOR-ized Data

- Thanks to the Climate Model Output Rewriter (CMOR), data in CMIP5 have a uniform format.
  - Clear-sky (condensate free) Ts, T, Q, CO_2, O_3, CH_4, N_2O.
  - Aerosols (Total aerosol, carbonaceous, dust, sea-salt, sulfate optical depths).
  - Clouds (Fractional area coverage, liq/ice distribution).
  - Surface boundary conditions (Snow cover, sea-ice cover, land fraction).
- These fields have been adapted externally to be consistent with the existing OSSE framework.

Hyperspectral Results

- In Arctic, window bands in SW and LW differentiate models.
  - With individual channels, 10 year detection time without measurement uncertainty.
- In TWP, window bands + NIR H2O in SW and LW differentiate models.
  - With individual channels, 10 year detection time, without measurement uncertainty.
- Using PCs, we can exploit correlations of spectra and dipole responses to improve detection times.



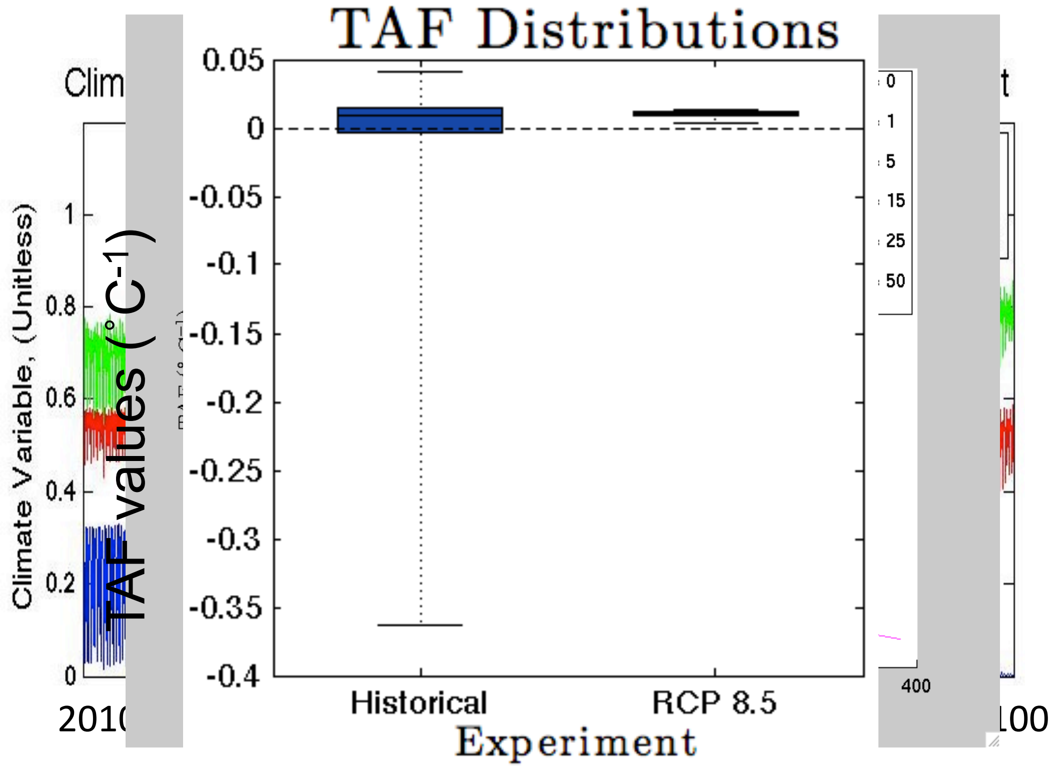
Feldman, et al, GMD In Prep

Intermodel Difference Detection

- A data record can differentiate 2 models in under 10 years based on vis window, nir H2O, and ir window.
  - Focus should be on few key locations because model response in these locations is so disparate.
  - Caveat: bootstrapping and validation with CFMIP quite challenging.
- For more subtle signals, how much longer are detection times?

Diagnosis of Arctic Feedbacks in CMIP5

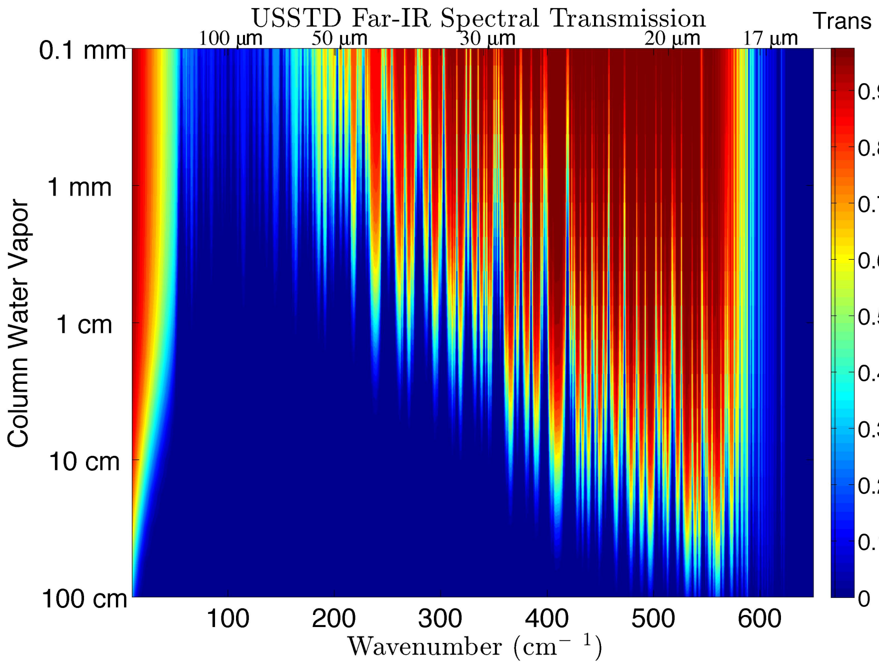
- Using APRP method of Taylor, diagnose cloud feedbacks in the Arctic from the CMIP5 database where albedo is stable despite loss of frozen surface extent.
- Determine how flux measurements can differentiate model outliers.
  - Requires TOA and surface fluxes.

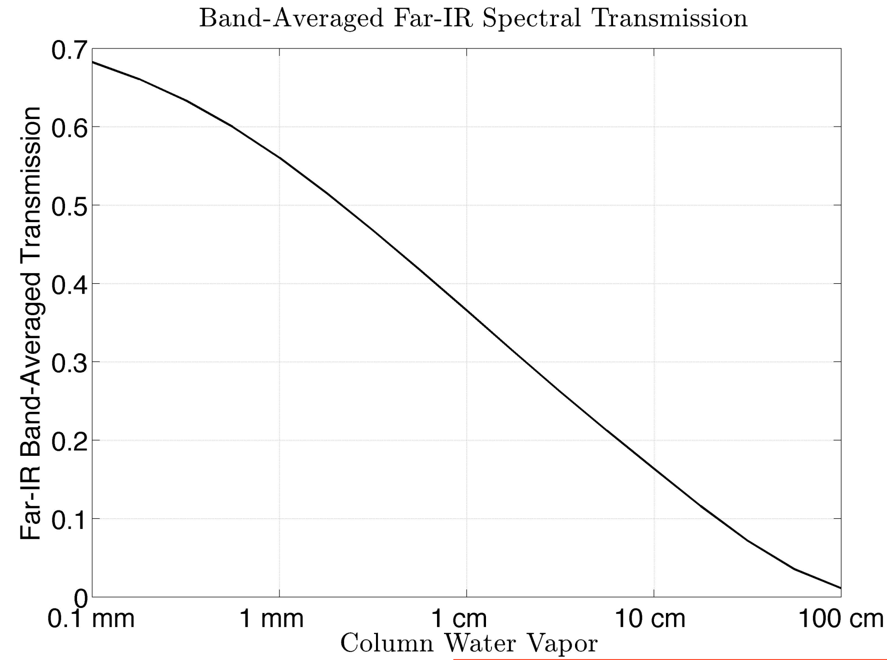


Paige and Feldman, in Prep

Other Research Highlights: $\varepsilon_{far\text{-}ir}$

- For moist conditions, surface emissivity at wavelengths >15 μm does not impact radiation budget.
- For dry conditions, $\varepsilon_{far\text{-}ir}$ ***DOES*** impact radiation budget as atmosphere becomes more transparent through microwindows starting at 550 cm^{-1}.

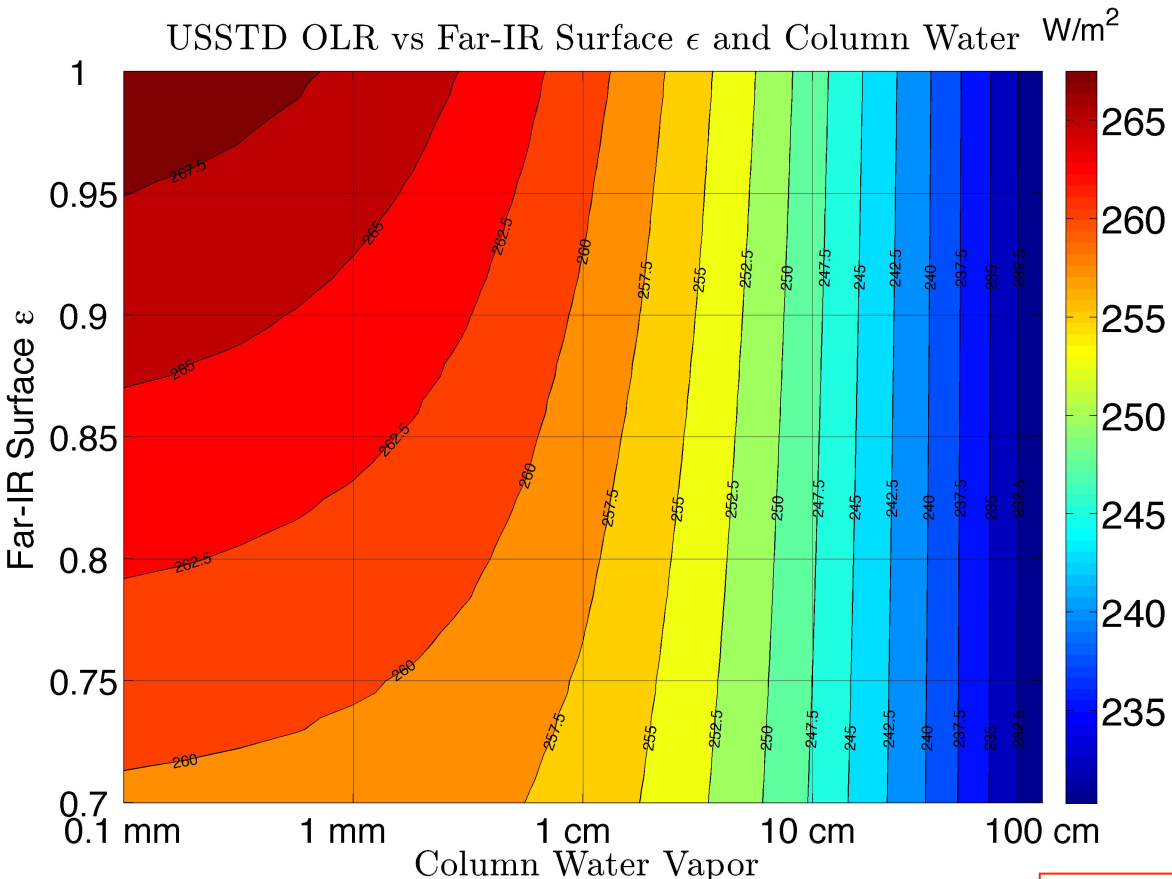




Feldman, et al, PNAS Submitted

$\varepsilon_{far\text{-}ir}$ impacts OLR

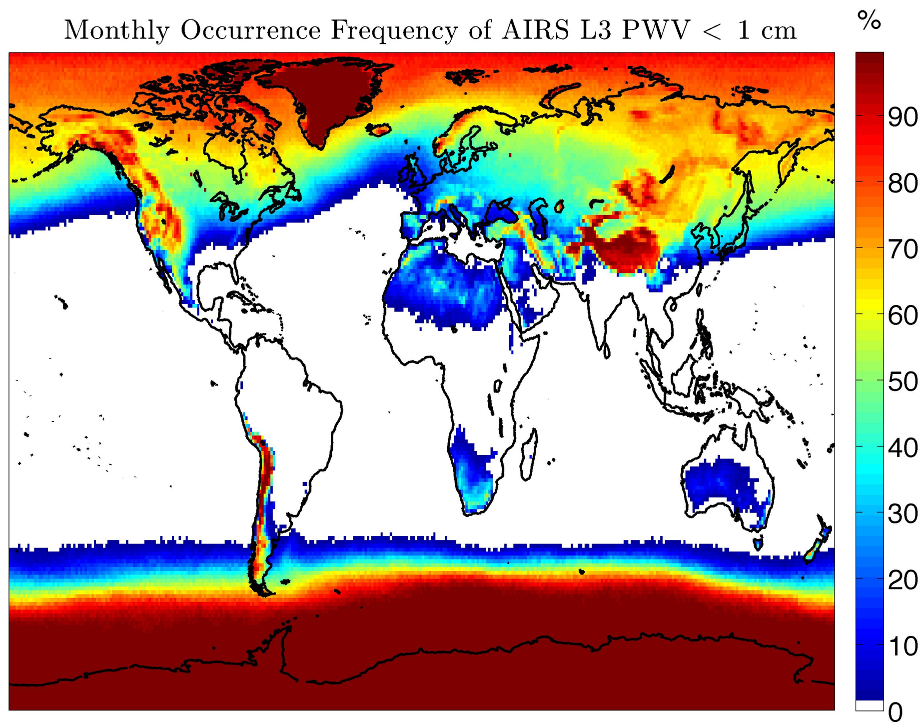
- Below 1 cm^{-1} PWV, OLR is a strong function of $\varepsilon_{far\text{-}ir}$.



Feldman, et al, PNAS Submitted

Dry Conditions are Common

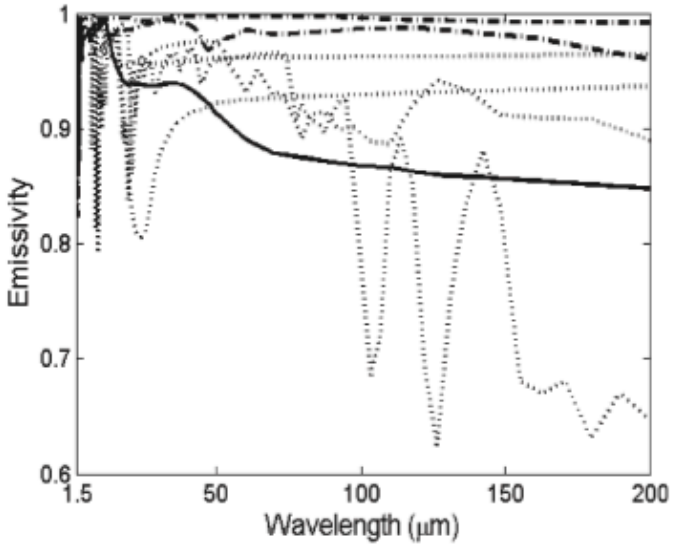
- AIRS indicates that high latitudes and altitudes are regularly dry enough such that $\varepsilon_{far\text{-}ir}$ matters.

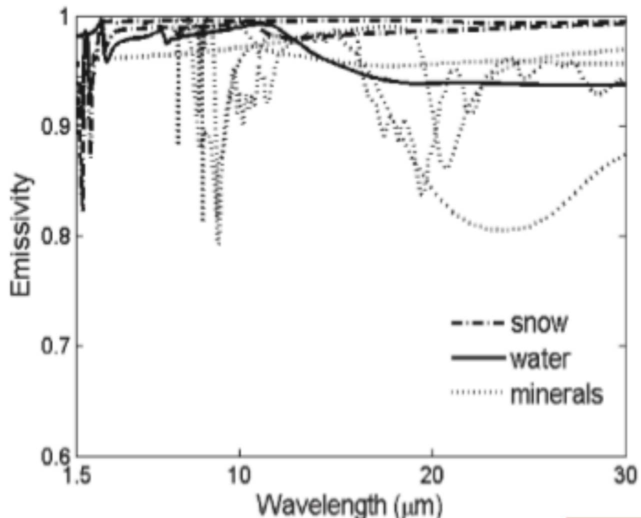


Feldman, et al, PNAS Submitted

Few Measurements of $\varepsilon_{far\text{-}ir}$

- The published literature indicates that $\varepsilon_{far\text{-}ir}$ is a function of surface minerology.
- From U of Mich: $\varepsilon_{far\text{-}ir}$ is a function of snow grain size.
- Very few measurements, assumed to be 1.0 in climate models.
- Could be retrieved from single scenes with CLARREO far-IR spectrometer.
- No publication to justify extrapolation from mid-IR to far-IR (burden of proof is now on the extrapolator).



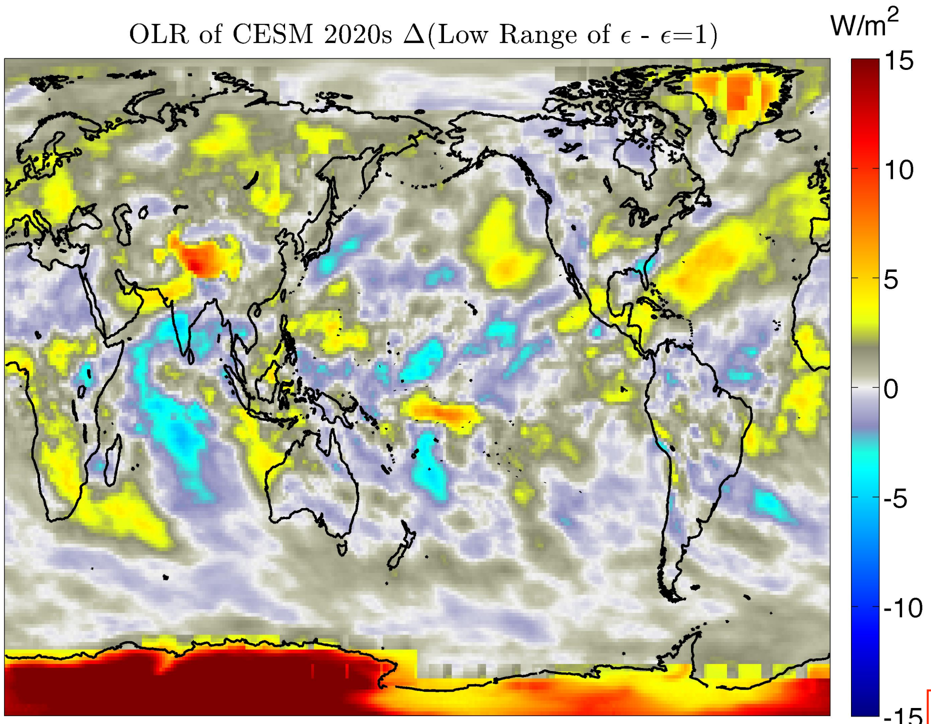


Cheng et al, 2013

Climate Models Underspecify $\varepsilon_{far\text{-}ir}$

- Climate models do not specify $\varepsilon_{far\text{-}ir}$ yet they are sensitive to it.
- Setting land $\varepsilon_{far\text{-}ir}$ to low value in Cheng et al, 2013 leads to: 2°K ΔT_s, 15 W/m^2 ΔOLR, and 15% Δice/snow fraction, after only 15 years of integration.

OLR of CESM 2020s Δ(Low Range of ϵ - ϵ=1)



Feldman, et al, PNAS Submitted

Conclusions

- The OSSE is able to utilize CMOR-ized inputs to calculate SW reflectance and LW radiance
  - Validation activities are ongoing.
- Models of disparate climate sensitivities can be differentiated in under 10 years in TWP and Arctic.
- However, understanding interaction between clouds and frozen surfaces from conventional measurements takes many decades.
- CLARREO IR can produce far-IR emissivity immediately which cannot be extrapolated from mid-IR.

Future Research Directions and Collaborations

- Radiometric validation of CMIP5 OSSE using CFMIP.
- Differentiation of low- and mid-sensitivity CMIP5 models.
- Pan-spectral PCA detection (with Yolanda).
- Detection analysis with AIRS spectral fluxes.
- Utilize spectral fingerprinting with OSSE data.